PB-240 938

THORNAPPLE LAKE, BARRY COUNTY, MICHIGAN

Pacific Northwest Environmental Research Laboratory

Prepared for:

National Environmental Research Center
Michigan Department of Natural Resources
Michigan National Guard

March 1975

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16. ABSTRACT

Annual total phosphorus and total nitrogen loadings to the lake were estimated and subdivded according to either point or non-point source origin. An assessment of the lake's trophic condition and limiting nutrient is also provided. All data collected by the U.S.E.P.A. National Eutrophication Survey during the one year study of the lake and its tributaries are included in the report.

17. KEY WORDS AND DOCUMENT ANALYSIS

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REPORT

ON

THORNAPPLE LAKE

BARRY COUNTY

MICHIGAN

EPA REGION V

WORKING PAPER No. 215

WITH THE COOPERATION OF THE

MICHIGAN DEPARTMENT OF NATURAL RESOURCES

AND THE

MICHIGAN NATIONAL GUARD

MARCH, 1975

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FOREWORD

The National Eutrophication Survey was initiated in 1972 in response to an Administration commitment to investigate the nationwide threat of accelerated eutrophication to fresh water lakes and reservoirs.

OBJECTIVES

The Survey was designed to develop, in conjunction with state environmental agencies, information on nutrient sources, concentrations, and impact on selected freshwater lakes as a basis for formulating comprehensive and coordinated national, regional, and state management practices relating to point-source discharge reduction and non-point source pollution abatement in lake watersheds.

ANALYTIC APPROACH

The mathematical and statistical procedures selected for the Survey's eutrophication analysis are based on related concepts that:

a. A generalized representation or model relating sources, concentrations, and impacts can be constructed.

b. By applying measurements of relevant parameters associated with lake degradation, the generalized model can be transformed into an operational representation of a lake, its drainage basin, and related nutrients.

c. With such a transformation, an assessment of the potential for eutrophication control can be made.

LAKE ANALYSIS

In this report, the first stage of evaluation of lake and watershed data collected from the study lake and its drainage basin is documented. The report is formatted to provide state environmental agencies with specific information for basin planning [§303(e)], water quality criteria/standards review [§303(c)], clean lakes [§314(a,b)], and water quality monitoring [§106 and §305(b)] activities mandated by the Federal Water Pollution Control Act Amendments of 1972.

Beyond the single lake analysis, broader based correlations between nutrient concentrations (and loading) and trophic condition are being made to advance the rationale and data base for refinement of nutrient water quality criteria for the Nation's fresh water lakes. Likewise, multivariate evaluations for the relationships between land use, nutrient export, and trophic condition, by lake class or use, are being developed to assist in the formulation of planning guidelines and policies by EPA and to augment plans implementation by the states.

ACKNOWLEDGMENT

The staff of the National Eutrophication Survey (Office of Research & Development, U. S. Environmental Protection Agency) expresses sincere appreciation to the Michigan Department of Natural Resources for professional involvement and to the Michigan National Guard for conducting the tributary sampling phase of the Survey.

A. Gene Gazlay, former Director, and David H. Jenkins, Acting Director, Michigan Department of Natural Resources; Carlos Fetterolf, Chief Environmental Scientist, Bureau of Water Management; and John Robinson, Chief, Dennis Tierney, Aquatic Biologist, and Albert Massey, Aquatic Biologist, Water Quality Appraisal Section, Bureau of Water Management, Department of Natural Resources, provided invaluable lake documentation and counsel during the course of the Survey. John Vogt, Chief of the Bureau of Environmental Health, Michigan Department of Public Health, and his staff were most helpful in identifying point sources and soliciting municipal participation in the Survey.

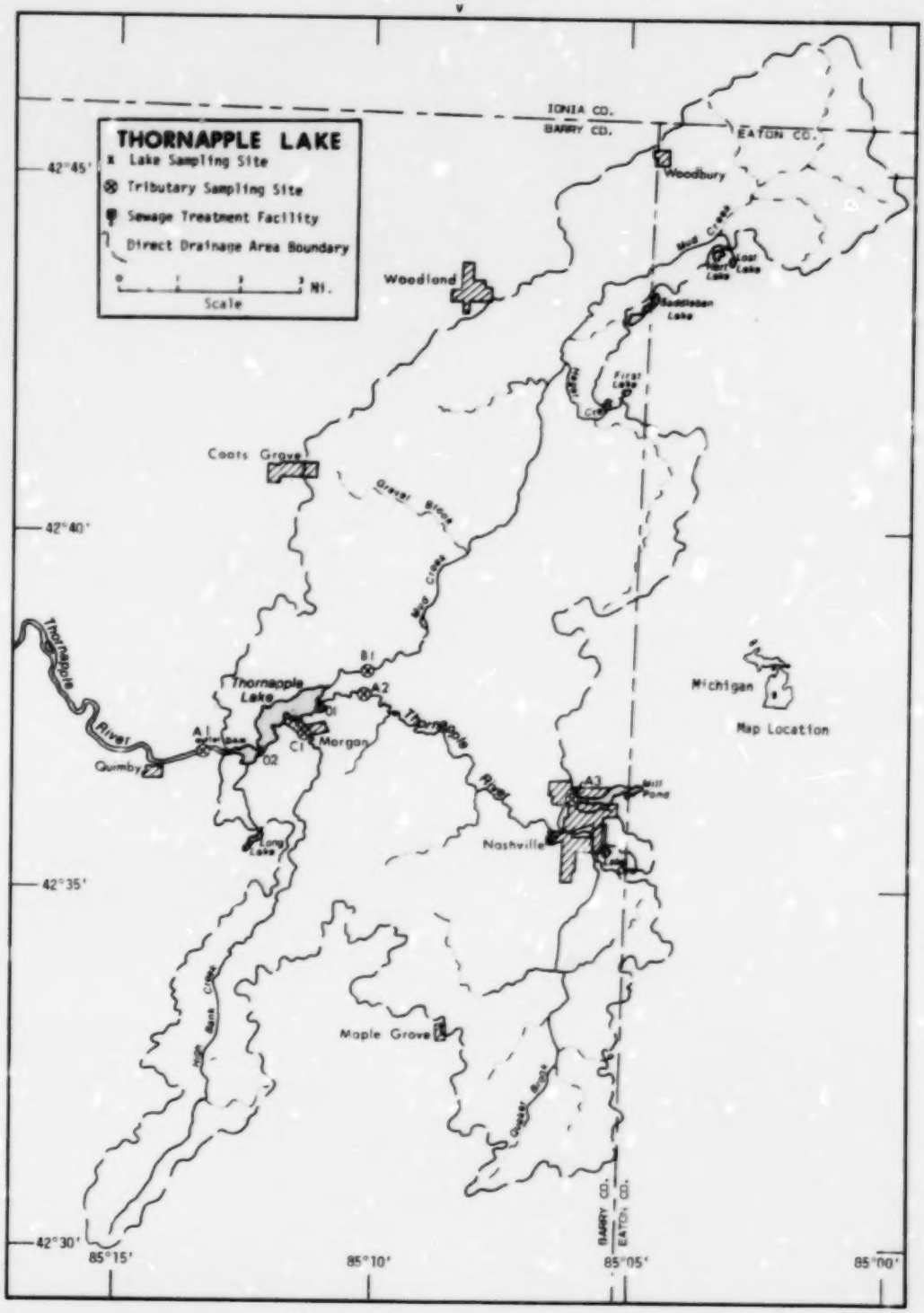
Major General Clarence A. Schnipke (Retired), then the Adjutant General of Michigan, and Project Officer Colonel Albert W. Lesky, who directed the volunteer efforts of the Michigan National Guardsmen, are also gratefully acknowledged for their assistance to the Survey.

NATIONAL EUTROPHICATION SURVEY

STUDY LAKES

STATE OF MICHIGAN

LAKE NAME	COUNTY
Allegan Res.	Allegan
Barton	Kalamazoo
Belleville	Wayne
Betsie	Benzie
Brighton	Livingston
Caro Res.	Tuscola
Charlevoix	Charlevoix
Chemung	Livingston
Constantine Res.	St. Joseph
Crystal	Montcalm
Deer	Marquette
Ford	Washtenaw
Fremont	Newago
Higgins	Roscommon
Holloway Res.	Genesee, Lapeer
Houghton	Roscommon
Jordon	Ionia, Barry
Kent	Oakland
Long	St. Joseph
Macatawa	Ottawa
Manistee	Manistee
Mona	Muskegon
Muskegon	Muskegon
Pentwater	Oceana
Pere Marquette	Mason
Portage	Houghton
Randall	Branch
Rogers Pond	Mecosta
Ross	Gladwin
St. Louis Res.	Gratiot
Sanford	Midland
Strawberry	Livingston
Thompson	Livingston
Thornapple	Barry
Union	Branch
White	Muskegon


THORNAPPLE LAKE
Lake Sampling Site
Tributary Sampling Site
Sewage Treatment Facility
Direct Drainage Area Boundary
Scale
Mi.
IONIA CO.
BARRY CO.
EATON CO.
42°45'
42°40'
42°35'
42°30'
85°15'
85°10'
85°05'
85°00'
Woodbury
Woodland
Coats Grove
Gravel Brook
Thornapple River
Thornapple Lake
Morgan
Qumby
Nashville
Mill Pond
Long Lake
Maple Grove
Michigan
Map Location
B1
A2
A1
A3
C1
01
02

THORNAPPLE LAKE

STORET NO 2683

I. CONCLUSIONS

A. Trophic Condition:

Survey data show that Thornapple Lake is eutrophic. Of the 35 Michigan lakes sampled in November when essentially all were well-mixed, 15 had less mean total phosphorus, 18 had less mean dissolved phosphorus, and only three lakes had more mean inorganic nitrogen; of all 41 lakes sampled, 20 had greater Secchi disc transparency, and 25 had less mean chlorophyll a*. Dissolved oxygen was depleted at both stations at the 4-foot level in September.

Survey limnologists noted an algal bloom in progress in September.

B. Rate-Limiting Nutrient:

A significant loss of phosphorus occurred in the algal assay sample, and the results are not representative of conditions in the lake at the time the sample was taken.

The lake data indicate nitrogen limitation in June and September but phosphorus limitation in November.

C. Nutrient Controllability:

1. Point sources--During the sampling year, Thornapple Lake received a total phosphorus load at a rate over four times

* See Appendix A.

that proposed by Vollenweider (in press) as "dangerous"; i.e., a eutrophic rate (see page 12). However, it is probable that Vollenweider's model does not apply to water bodies with short hydraulic retention times. Thornapple Lake has a mean hydraulic retention time of only 11 days, and it is likely that the model is not applicable.

It is calculated that the Village of Nashville contributed 6.5% of the total phosphorus load to the lake during the sampling year. While complete removal of phosphorus at this source would only reduce the loading rate to about 6 $g/m^2/yr$, it is possible that a high degree of phosphorus removal would result in persistent phosphorus limitation (see page 7) and a reduction in the incidence and severity of nuisance algal blooms. However, it appears that a significant improvement in the trophic condition of the lake will require reduction of the phosphorus loads from other sources as well (see below).

2. Non-point sources--During the sampling year, the mean phosphorus export rate of the Thornapple Lake tributaries was a relatively high 87 pounds per square mile (see page 12), and Mud Creek had a particularly high export rate of 112 lbs/mi^2.

It is believed that the high export rate of Mud Creek is due to four known point sources beyond the 25-mile limit of the

Survey*; and, if a marked improvement in the trophic condition of Thornapple Lake is to be achieved, all phosphorus inputs will have to be minimized to the greatest practicable degree.

* See Working Paper No. 1, "Survey Methods, 1972".

II. LAKE AND DRAINAGE BASIN CHARACTERISTICS

A. Lake Morphometry†:

1. Surface area: 409 acres.
2. Mean depth: 13.9 feet.
3. Maximum depth: 31 feet.
4. Volume: 5,685 acre-feet.
5. Mean hydraulic retention time: 11 days.

B. Tributary and Outlet:
(See Appendix B for flow data)

1. Tributaries -

Name	Drainage area*	Mean flow*
Thornapple River	260.0 mi^2	187.9 cfs
Mud Creek	57.6 mi^2	41.8 cfs
High Bank Creek	33.9 mi^2	24.6 cfs
Minor tributaries & immediate drainage -	7.9 mi^2	6.5 cfs
Totals	359.4 mi^2	260.8 cfs

2. Outlet -

Thornapple River**	360.0 mi^2**	260.8 cfs**

C. Precipitation***:

1. Year of sampling: 34.6 inches.
2. Mean annual: 32.4 inches.

† MI Dept. Cons. lake inventory map (1949); mean depth by random-dot method.
* Drainage areas are accurate within ±5%; mean daily flows for 74% of the sampling sites are accurate within ±25% and the remaining sites up to ±40%; and mean monthly flows, normalized mean monthly flows, and mean annual flows are slightly more accurate than mean daily flows.
** Includes area of lake; outflow adjusted to equal sum of inflows.
*** See Working Paper No. 1.

III. LAKE WATER QUALITY SUMMARY

Thornapple Lake was sampled three times during the open-water season of 1972 by means of a pontoon-equipped Huey helicopter. Each time, samples for physical and chemical parameters were collected from two stations on the lake and from a number of depths at each station (see map, page v). During each visit, a single depth-integrated (15 feet or near bottom to surface) sample was composited from the stations for phytoplankton identification and enumeration; and during the second visit, a single five-gallon depth-integrated sample was composited for algal assays. Also each time, a depth-integrated sample was collected from each of the stations for chlorophyll *a* analysis. The maximum depths sampled were 11 feet at station 1 and 20 feet at station 2.

The results obtained are presented in full in Appendix C, and the data for the fall sampling period, when the lake essentially was well-mixed, are summarized below. Note, however, the Secchi disc summary is based on all values.

For differences in the various parameters at the other sampling times, refer to Appendix C.

A. Physical and chemical characteristics:

Parameter	Minimum	Mean	Median	Maximum
		FALL VALUES (11/14/72)		
Temperature (Cent.)	5.6	5.7	5.6	5.8
Dissolved oxygen (mg/l)	9.1	9.6	9.2	10.4
Conductivity (μmhos)	585	593	590	600
pH (units)	7.7	7.7	7.7	7.7
Alkalinity (mg/l)	170	201	200	250
Total P (mg/l)	0.035	0.042	0.043	0.049
Dissolved P (mg/l)	0.028	0.032	0.034	0.039
NO_2 + NO_3 (mg/l)	1.530	1.644	1.640	1.780
Ammonia (mg/l)	0.050	0.093	0.120	0.130
		ALL VALUES		
Secchi disc (inches)	32	57	60	84

B. Biological characteristics:

1. Phytoplankton* -

Sampling Date	Dominant Genera	Number per ml
09/18/72	1. Lyngbya	2,620
	2. Synedra	1,084
	3. Microcystis	904
	4. Flagellates	632
	5. Mallomonas	542
	Other genera	2,622
	Total	8,404
11/14/72	1. Flagellates	803
	2. Aphanothece	582
	3. Raphidiopsis	150
	4. Fragilaria	110
	5. Dinobryon	100
	Other genera	363
	Total	2,108

* The June sample was lost in shipment.

2. Chlorophyll a -
(Because of instrumentation problems during the 1972 sampling, the following values may be in error by plus or minus 20 percent.)

Sampling Date	Station Number	Chlorophyll a (µg/l)
06/13/72	01	30.7
	02	24.2
09/18/72	01	20.6
	02	11.3
11/14/72	01	0.4
	02	0.7

C. Limiting Nutrient Study:

There was a loss of about 55% of the dissolved phosphorus in the algal assay sample from the time of collection to the time the assay was begun, and the results are not representative of conditions in the lake at the time the sample was taken.

The lake data indicate nitrogen limitation in June and September (N/P ratios were 9/1 and 12/1, respectively) but phosphorus limitation in November (N/P ratio = 54/1).

IV. NUTRIENT LOADINGS
(See Appendix D for data)

For the determination of nutrient loadings, the Michigan National Guard collected monthly near-surface grab samples from each of the tributary sites indicated on the map (page v), except for the high runoff months of April and May, when two samples were collected, and the colder months when one or more samples were omitted depending on the site. Sampling was begun in October, 1972, and was completed in September, 1973.

Through an interagency agreement, stream flow estimates for the year of sampling and a "normalized" or average year were provided by the Michigan District Office of the U.S. Geological Survey for the tributary sites nearest the lake.

In this report, nutrient loads for sampled tributaries were determined by using a modification of a U.S. Geological Survey computer program for calculating stream loadings*. Nutrient loadings for unsampled "minor tributaries and immediate drainage" ("ZZ" of U.S.G.S.) were estimated by using the means of the nutrient loads, in lbs/mi^2/year, in High Bank Creek at station C-1 and multiplying the means by the ZZ area in mi^2.

The operator of the Nashville wastewater treatment plant provided monthly effluent samples and corresponding flow data, and it is assumed

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* See Working Paper No. 1.

the entire nutrient load from this plant reached Thornapple Lake during the sampling year.

The nutrient loads attributed to the Thornapple River are those measured at station A-2 minus the Nashville loads.

A. Waste Sources:

1. Known municipal* -

Name	Pop. Served	Treatment	Mean Flow (mgd)	Receiving Water
Nashville	1,558**	Imhoff	0.121	Thornapple River

2. Known industrial - None

* Cowles, 1973.
** 1970 Census.

B. Annual Total Phosphorus Loading - Average Year:

1. Inputs -

Source	lbs P/ yr	% of total
a. Tributaries (non-point load) -		
Thornapple River	22,300	66.2
Mud Creek	6,450	19.1
High Bank Creek	2,130	6.3
b. Minor tributaries & immediate drainage (non-point load) -	500	1.5
c. Known municipal STP's -		
Nashville	2,200	6.5
d. Septic tanks* -	60	0.2
e. Known industrial - None	-	-
f. Direct precipitation** -	60	0.2
Total	33,700	100.0

2. Outputs -

Lake outlet - Thornapple River 26,610

3. Net annual P accumulation - 7,090 pounds

* Estimate based on 100 lakeshore dwellings; see Working Paper No. 1.
** See Working Paper No. 1.

C. Annual Total Nitrogen Loading - Average Year:

1. Inputs -

Source	lbs N/ yr	% of total
a. Tributaries (non-point load) -		
Thornapple River	708,340	75.6
Mud Creek	154,730	16.5
High Bank Creek	49,380	5.3
b. Minor tributaries & immediate drainage (non-point load) -	11,510	1.2
c. Known municipal STP's -		
Nashville	7,210	0.8
d. Septic tanks* -	2,350	0.2
e. Known industrial - None	-	-
f. Direct precipitation** -	3,940	0.4
Total	937,460	100.0

2. Outputs -

Lake outlet - Thornapple River 828,330

3. Net annual N accumulation - 109,130 pounds

* Estimate based on 100 lakeshore dwellings; see Working Paper No. 1.
** See Working Paper No. 1.

D. Mean Annual Non-point Nutrient Export by Subdrainage Area:

Tributary	lbs P/mi^2/yr	lbs N/mi^2/yr
Thornapple River	86	2,724
Mud Creek	112	2,686
High Bank Creek	63	1,457

E. Yearly Loading Rates:

In the following table, the existing phosphorus loading rates are compared to those proposed by Vollenweider (in press). Essentially, his "dangerous" rate is the rate at which the receiving waters would become eutrophic or remain eutrophic; his "permissible" rate is that which would result in the receiving water remaining oligotrophic or becoming oligotrophic if morphometry permitted. A mesotrophic rate would be considered one between "dangerous" and "permissible".

Note that Vollenweider's model may not be applicable to water bodies with very short hydraulic retention times.

	Total Phosphorus		Total Nitrogen	
Units	Total	Accumulated	Total	Accumulated
lbs/acre/yr	82.4	17.3	2,303.9	278.8
grams/m^2/yr	9.24	1.94	258.2	31.2

Vollenweider loading rates for phosphorus (g/m^2/yr) based on mean depth and mean hydraulic retention time of Thornapple Lake:

"Dangerous" (eutrophic rate)	2.20
"Permissible" (oligotrophic rate)	1.10

V. LITERATURE REVIEWED

Cowles, Fred E., 1973. Treatment plant questionnaire (Nashville STP). MI Dept. Publ. Health, Lansing.

Vollenweider, Richard A. (in press). Input-output models. Schweiz. Z. Hydrol.

VI. APPENDICES

APPENDIX A

LAKE RANKINGS

LAKE DATA TO BE USED IN RANKINGS

LAKE CODE	LAKE NAME	FALL VALUES MEAN TOTAL P	FALL VALUES MEAN DISS P	FALL VALUES MEAN INORG N	ALL VALUES 500- MEAN SEC	ALL VALUES MEAN CHLORA	ALL VALUES 15- MIN DO
2640	HOLLOWAY RESERVOIR	0.062	0.043	1.461	439.375	10.670	9.200
2641	CARO RESERVOIR	0.117	0.022	3.035	473.000	11.967	9.500
2642	BOARDMAN HYDRO POND	0.006	0.005	0.358	363.500	1.267	6.600
2603	ALLEGAN LAKE	0.123	0.057	1.168	470.222	20.311	12.600
2606	BARTON LAKE	0.121	0.006	1.489	456.167	27.800	14.850
2609	BELLEVILLE LAKE	0.110	0.048	1.420	465.250	20.262	8.200
2610	BETSIE LAKE	0.025	0.008	0.273	461.667	4.567	7.400
2613	BRIGHTON LAKE	0.109	0.073	1.015	456.000	44.233	7.550
2617	LAKE CHARLEVOIX	0.067	0.006	0.230	351.250	3.000	9.240
2618	LAKE CHEMUNG	0.044	0.014	0.132	404.333	13.483	14.800
2621	CONSTANTINE RESERVOIR	0.027	0.008	0.910	456.167	39.317	7.500
2629	FORD LAKE	0.105	0.050	1.536	456.167	14.733	14.800
2631	FREMONT LAKE	0.372	0.342	1.406	441.667	28.500	14.800
2640	JORDAN LAKE	0.180	0.144	1.998	427.667	28.517	14.900
2643	KENT LAKE	0.040	0.015	0.417	455.000	33.944	13.000
2648	LAKE MACATAWA	0.197	0.120	2.358	477.600	25.600	12.200
2649	MANISTEE LAKE	0.018	0.018	0.304	451.333	6.317	11.360
2659	MUSKEGON LAKE	0.087	01043	0.469	430.444	9.511	14.800
2665	PENTWATER LAKE	0.027	0.017	0.496	430.667	14.083	14.800
2671	RANDALL LAKE	0.246	0.183	0.818	457.333	27.217	8.020
2672	ROGERS POND	0.026	0.015	0.183	435.500	8.133	9.600
2673	RUSS RESERVOIR	0.034	0.021	0.460	465.333	10.383	8.200
2674	SANFORD LAKE	0.016	0.008	0.327	458.750	13.791	8.300
2683	THORNAPPLE LAKE	0.042	0.032	1.737	442.833	14.650	10.800
2685	UNION LAKE	0.083	0.064	1.252	455.500	15.667	8.200
2688	WHITE LAKE	0.027	0.019	0.367	417.778	9.211	13.400
2691	MONA LAKE	0.307	0.241	0.963	451.667	27.783	14.100
2692	LONG LAKE	0.163	0.148	0.749	418.400	10.067	13.600

LAKE DATA TO BE USED IN RANKINGS

LAKE CODE	LAKE NAME	FALL VALUES: MEAN TOTAL P	FALL VALUES: MEAN DISS P	FALL VALUES: MEAN INORG N	ALL VALUES: SOO-MEAN SEC	ALL VALUES: MEAN CHLOHA	ALL VALUES: 1S-MIN DO
2693	ST LOUIS HESERVOIR	0.134	0.093	1.227	462.667	5.583	8.420
2694	CHYSTAL LAKE	0.009	0.006	0.164	380.000	2.986	13.000
2695	HIGGINS LAKE	0.007	0.005	0.058	268.500	1.043	9.400
2696	HOUGHTON LAKE	0.018	0.008	0.136	420.833	9.217	8.200
2697	THOMPSON LAKE	0.043	0.029	0.436	407.889	11.967	14.800
2698	PERE MARQUETTE LAKE	0.032	0.024	0.346	448.667	11.833	8.600
2699	STRAWBERRY LAKE	0.069	0.050	0.567	419.800	11.117	13.600

PERCENT OF LAKES WITH HIGHER VALUES (NUMBER OF LAKES WITH HIGHER VALUES)

LAKE CODE	LAKE NAME	----------FALL VALUES---------- MEAN TOTAL P	MEAN DISS P	MEAN INORG N	----------ALL VALUES---------- SUR-MEAN SEC	MEAN CHLORA	1S-MIN DO	INDEX NO
2640	HOLLOWAY RESERVOIR	46 (16)	43 (15)	17 (6)	57 (20)	60 (21)	63 (22)	246
2641	CARO RESERVOIR	20 (10)	54 (19)	9 (3)	3 (1)	49 (17)	54 (19)	189
2642	BOARDMAN HYDRO POND	97 (34)	97 (34)	69 (24)	91 (32)	94 (33)	97 (34)	545
2603	ALLEGAN LAKE	20 (7)	31 (11)	31 (11)	6 (2)	29 (10)	40 (14)	157
2606	BANTON LAKE	23 (8)	20 (7)	14 (5)	29 (9)	14 (5)	3 (1)	103
2609	BELLEVILLE LAKE	26 (9)	37 (13)	20 (7)	11 (4)	11 (4)	79 (26)	184
2610	BETSIE LAKE	77 (27)	77 (27)	80 (28)	17 (6)	86 (30)	94 (33)	431
2613	BRIGHTON LAKE	31 (11)	23 (8)	34 (12)	34 (12)	0 (0)	90 (31)	212
2617	LAKE CHARLEVOIX	91 (32)	91 (32)	83 (29)	94 (33)	89 (31)	60 (21)	508
2618	LAKE CHEMUNG	49 (17)	71 (25)	94 (33)	86 (30)	46 (16)	11 (2)	357
2621	CONSTANTINE RESERVOIR	71 (25)	83 (29)	40 (14)	29 (9)	3 (1)	90 (31)	316
2629	FORD LAKE	34 (12)	29 (10)	11 (4)	29 (9)	37 (13)	23 (8)	163
2631	FREMONT LAKE	0 (0)	0 (0)	23 (8)	54 (19)	9 (3)	11 (2)	97
2640	JORDAN LAKE	11 (4)	11 (4)	6 (2)	69 (24)	26 (9)	0 (0)	123
2643	KENT LAKE	57 (20)	69 (24)	63 (22)	40 (14)	6 (2)	36 (12)	271
2648	LAKE MACATAWA	9 (3)	14 (5)	3 (1)	0 (0)	23 (8)	43 (15)	92
2649	MANISTEE LAKE	80 (28)	74 (26)	77 (27)	46 (16)	80 (28)	46 (16)	403
2659	MUSKEGON LAKE	37 (13)	40 (14)	54 (19)	60 (21)	69 (24)	11 (2)	271
2665	PENTWATER LAKE	69 (24)	63 (22)	51 (18)	66 (23)	31 (11)	11 (2)	291
2671	RANDALL LAKE	6 (2)	6 (2)	43 (15)	23 (8)	20 (7)	86 (30)	184
2672	ROGERS POND	74 (26)	66 (23)	86 (30)	63 (22)	77 (27)	91 (10)	417
2673	RUSS RESERVOIR	60 (21)	57 (20)	57 (20)	9 (3)	63 (22)	74 (26)	320
2674	SANFORD LAKE	86 (30)	80 (28)	74 (26)	20 (7)	43 (15)	71 (25)	374
2683	THORNAPPLE LAKE	54 (19)	46 (16)	9 (3)	51 (18)	40 (14)	49 (17)	249
2685	UNION LAKE	40 (14)	26 (9)	26 (9)	37 (13)	34 (12)	79 (28)	242
2688	WHITE LAKE	66 (23)	60 (21)	66 (23)	80 (28)	74 (26)	31 (11)	377
2691	MONA LAKE	3 (1)	3 (1)	37 (13)	43 (15)	17 (6)	20 (7)	123
2692	LONG LAKE	14 (5)	9 (3)	46 (16)	77 (27)	66 (23)	27 (9)	239

PERCENT OF LAKES WITH HIGHER VALUES (NUMBER OF LAKES WITH HIGHER VALUES)

LAKE CODE	LAKE NAME	FALL VALUES: MEAN TOTAL P	FALL VALUES: MEAN DISS P	FALL VALUES: MEAN INORG N	ALL VALUES: 500- MEAN SEC	ALL VALUES: MEAN CHLORA	ALL VALUES: 15- MIN DO	INDEX NO
2693	ST LOUIS RESERVOIR	17 (6)	17 (6)	29 (10)	14 (5)	83 (29)	69 (24)	229
2694	CRYSTAL LAKE	89 (31)	89 (31)	89 (31)	89 (31)	91 (32)	36 (12)	483
2695	HIGGINS LAKE	94 (33)	94 (33)	97 (34)	97 (34)	97 (34)	57 (20)	536
2696	HOUGHTON LAKE	83 (29)	86 (30)	91 (32)	71 (25)	71 (25)	79 (26)	481
2697	THOMPSON LAKE	51 (18)	49 (17)	60 (21)	83 (29)	51 (18)	11 (2)	305
2698	PERE MARQUETTE LAKE	63 (22)	51 (18)	71 (25)	49 (17)	54 (19)	66 (23)	354
2699	STRAWBERRY LAKE	43 (15)	34 (12)	49 (17)	74 (26)	57 (20)	27 (9)	284

APPENDIX B

TRIBUTARY FLOW DATA

TRIBUTARY FLOW INFORMATION FOR MICHIGAN 2/3/75

LAKE CODE 2683 THORNAPPLE LAKE

TOTAL DRAINAGE AREA OF LAKE(SQ MI) 360.00

TRIBUTARY	SUB-DRAINAGE AREA(SQ MI)	NORMALIZED FLOWS(CFS) JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2683A1	360.00	273.00	295.00	609.00	538.00	392.00	209.00	115.00	89.00	97.00	137.00	166.00	214.00	260.98
2683A2	260.00	197.00	213.00	440.00	388.00	283.00	151.00	83.10	64.10	70.20	99.20	120.00	148.00	187.91
2683B1	57.60	43.70	47.10	97.40	86.60	62.70	33.40	18.40	14.20	15.60	22.00	26.50	34.30	41.80
2683C1	33.90	25.70	27.70	57.30	50.60	36.90	19.60	10.80	8.40	9.20	12.90	15.60	20.20	24.56
2683ZZ	8.50	6.80	7.40	15.20	13.40	9.80	5.20	2.90	2.20	2.40	3.40	4.10	5.40	6.51

SUMMARY

TOTAL DRAINAGE AREA OF LAKE = 360.00
SUM OF SUB-DRAINAGE AREAS = 360.00
TOTAL FLOW IN = 3131.60
TOTAL FLOW OUT = 3134.00

MEAN MONTHLY FLOWS AND DAILY FLOWS(CFS)

TRIBUTARY	MONTH	YEAR	MEAN FLOW	DAY	FLOW	DAY	FLOW
2683A1	10	72	274.00	28	597.00		
	11	72	485.00	28	463.00		
	12	72	510.00				
	1	73	982.00	8	1100.00		
	2	73	339.00	4	496.00	28	222.00
	3	73	435.00				
	4	73	718.00	6	954.00	20	449.00
	5	73	379.00	4	521.00	25	335.00
	6	73	328.00	10	587.00		
	7	73	277.00	4	583.00	27	138.00
	8	73	121.00	31	95.00		
	9	73	103.00	24	109.00		
2683A2	10	72	198.00	28	431.00		
	11	72	350.00	28	334.00		
	12	72	368.00				
	1	73	709.00	8	837.00		
	2	73	245.00	4	356.00	28	160.00
	3	73	675.00				
	4	73	518.00	6	688.00	20	324.00
	5	73	273.00	4	376.00	25	242.00
	6	73	237.00	8	254.00		
	7	73	200.00	4	421.00	27	100.00
	8	73	87.00	31	69.00		
	9	73	74.00	24	79.00		

TRIBUTARY FLOW INFORMATION FOR MICHIGAN 2/3/75

LAKE CODE 2683 THORNAPPLE LAKE

MEAN MONTHLY FLOWS AND DAILY FLOWS(CFS)

TRIBUTARY	MONTH	YEAR	MEAN FLOW	DAY	FLOW	DAY	FLOW	DAY	FLOW
268381	10	72	44.60	28	96.00				
	11	72	78.00	26	74.00				
	12	72	82.00						
	1	73	158.00	8	186.00				
	2	73	54.00	4	80.00	28	36.00		
	3	73	150.00						
	4	73	115.00	6	153.00	20	72.00		
	5	73	61.00	4	84.00				
	6	73	53.00	10	94.00				
	7	73	44.00	4	93.00	28	22.00		
	8	73	19.00	31	15.00				
	9	73	16.30	24	18.00				
2683C1	10	72	26.00	28	56.00				
	11	72	46.00	28	44.00				
	12	72	48.00						
	1	73	92.60	8	109.60				
	2	73	32.00	4	47.00	28	21.00		
	3	73	88.00						
	4	73	68.00	6	90.00	20	42.00		
	5	73	36.00	4	49.00	25	32.00		
	6	73	31.00	10	55.00				
	7	73	26.00	4	55.00	27	13.00		
	8	73	11.00	31	9.00				
	9	73	9.70	24	10.00				
2683Z2	10	72	6.40						
	11	72	11.00						
	12	72	12.00						
	1	73	23.00						
	2	73	8.00						
	3	73	22.00						
	4	73	17.00						
	5	73	8.90						
	6	73	7.70						
	7	73	6.50						
	8	73	2.40						
	9	73	2.40						

APPENDIX C

PHYSICAL and CHEMICAL DATA

STORET RETRIEVAL DATE 75/02/04

268301
42 37 30.0 085 11 00.0
THORNAPPLE LAKE
26 MICHIGAN

11EPALES 2111202
5 0011 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00010 WATER TEMP CENT	00300 DO MG/L	00077 TRANSP SECCHI INCHES	00094 CNDUCTVY FIELD MICROMHO	00400 PH SU	00410 T ALK CACO3 MG/L	00630 NO2&NO3 N-TOTAL MG/L	00610 NH3-N TOTAL MG/L	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P
72/06/13	09 55	0000	19.4	11.0	60	600	8.40	263	0.090	0.050	0.026	0.019
	09 55	0006	18.5	9.7		600	8.45	272	0.160	0.040	0.029	0.019
	09 55	0011	17.5	7.0		620	8.10	276	0.210	0.160	0.050	0.034
72/09/14	14 30	0000			32	540	8.55	250	0.390	0.070	0.050	0.027
	14 30	0004		0.0		550	8.35	246	0.430	0.060	0.055	0.029
	14 30	0011	19.0	0.0		550	8.43	238	0.350	0.060	0.056	0.022
72/11/14	16 25	0000			84	600	7.70	180	1.670	0.050	0.036	0.028
	16 25	0004	5.8	10.4		600	7.70	170	1.640	0.050	0.035	0.028
	16 25	0008	5.7	10.3		600	7.70	200	1.780	0.050	0.038	0.028

23

DATE FROM TO	TIME OF DAY	DEPTH FEET	32217 CHLRPHYL A UG/L
72/06/13	09 55	0000	30.7J
72/09/14	14 30	0000	20.5J
72/11/14	16 25	0000	0.4J

J VALUE KNOWN TO BE IN ERROR

STORET RETRIEVAL DATE 75/02/04

268302
42 37 00.0 085 11 30.0
THORNAPPLE LAKE
26 MICHIGAN

11EPALES 2111202
5 0018 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00010 WATER TEMP CENT	00300 DO MG/L	00077 TRANSP SECCHI INCHES	00094 CNDUCTVY FIELD MICROMHO	00400 PH SU	00410 T ALK CACO3 MG/L	00630 NO2&NO3 N-TOTAL MG/L	00610 NH3-N TOTAL MG/L	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P
72/06/13	10	23 0000	19.5	9.8	72	600	8.40	268	0.130	0.060	0.019	0.010
	10	23 0010	19.0	9.9		610	8.15	272	0.110	0.170	0.045	0.033
	10	23 0015	12.8	4.2		560	7.85	256	0.020	0.170	0.059	0.043
	10	23 0018	12.1	0.0		540	7.80	256	0.070	0.460	0.111	0.055
72/09/18	15	00 0000			35	530	8.65	248	0.100	0.060	0.046	0.023
	15	00 0004	18.9	0.0		525	8.45	260	0.120	0.050	0.039	0.015
	15	00 0015	17.3	0.0		550	8.00	268	0.110	0.650	0.123	0.081
72/11/14	16	00 0000			60	590	7.70	180	1.530	0.120	0.049	0.039
	16	00 0004	5.6	9.2		590	7.70	210	1.560	0.120	0.043	0.035
	16	00 0015	5.6	9.1		585	7.70	220	1.630	0.130	0.045	0.035
	16	00 0020	5.6	9.2		585	7.70	250	1.700	0.130	0.048	0.034

24

DATE FROM TO	TIME OF DAY	DEPTH FEET	32217 CHLRPHYL A UG/L
72/06/13	10	23 0000	24.2J
72/09/18	15	00 0000	11.3J
72/11/14	16	00 0000	0.7J

J VALUE KNOWN TO BE IN ERROR

APPENDIX D

TRIBUTARY and WASTEWATER TREATMENT PLANT DATA

STORET RETRIEVAL DATE 75/02/04

26H3A1 LS2683A1
42 37 00.0 085 12 30.0
THORNAPPLE RIVER
26 15 NASHVILLE
0/THORNAPPLE LAKE
BRDG 1 MI NE OF GUIMBY
11EPALES 2111204
4 0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
73/01/08	15 09		2.700	1.380	0.042	0.042	0.077
73/02/04	12 15		1.520	0.560	0.028	0.013	0.030
73/02/28	07 55		1.120	0.540	0.060	0.012	0.030
73/04/06	12 26		1.020	0.800	0.031	0.009	0.040
73/04/20	14 53		0.600	0.687	0.013	0.005K	0.025
73/05/04	12 15		0.300	0.915	0.016	0.009	0.065
73/05/25	15 20		0.100	0.920	0.011	0.012	0.035
73/06/10	17 00		0.480	1.300	0.035	0.034	0.085
73/07/04	19 50		0.700	1.150	0.082	0.026	0.070
73/07/27	11 35		0.021	0.820	0.009	0.005K	0.025
73/08/31	11 45		0.010K	0.570	0.011	0.005K	0.030
73/09/24	12 55		0.046	0.900	0.058	0.038	0.100

26

K VALUE KNOWN TO BE
LESS THAN INDICATED

STORET RETRIEVAL DATE 73/02/04

25H3A2 LS26H3A2
42 38 00.0 085 09 30.0
THORNAPPLE RIVER
26 15 NASHVILLE
T/THORNAPPLE LAKE
BRDG 23/4 MI NW NASHVILLE BELOW STP
11EPALES 2111204
4 0000 FEET DEPTH

27

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
72/10/28	09 50		1.400	2.250	0.150	0.044	0.081
72/11/28	14 40		0.420	0.580	0.015	0.016	0.030
73/01/08	15 28		2.900	1.260	0.050	0.036	0.061
73/02/04	17 35		1.440	0.460	0.033	0.018	0.035
73/02/28	08 10		1.000	0.480	0.048	0.016	0.045
73/04/06	12 05		1.120	0.650	0.018	0.009	0.025
73/04/20	14 28		0.680	0.720	0.019	0.011	0.035
73/05/04	12 35		0.620	1.890	0.044	0.020	0.065
73/05/25	15 00		0.590	1.300	0.064	0.023	0.065
73/06/08	12 00		0.840	1.400	0.078	0.054	0.090
73/07/04	19 30		1.040	1.260	0.057	0.040	0.130
73/07/27	11 12		0.290	0.630	0.030	0.046	0.090
73/08/31	11 23		0.270	0.420	0.039	0.053	0.095
73/09/24	13 10		0.310	0.340	0.063	0.034	0.065

STORET RETRIEVAL DATE 75/02/04

```
 26ddJA3          LS26ddJA3
42 30 30.0 085 05 30.0
THORNAPPLE RIVER
26       15 NASHVILLE
T/THORNAPPLELAKE
BRDG AT N EDGE OF NASHVILLEABOVE STP
11EPALES                 21112U4
4                        0000 FEET  DEPTH
```

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
72/10/28	09 15		1.500	0.350	0.088	0.039	0.075
72/11/28	14 30		0.350	0.600	0.012	0.016	0.031
73/01/08	14 54		3.000	1.200	0.027	0.032	0.059
73/02/04	17 50		1.540	0.480	0.028	0.012	0.030
73/04/06	11 55		1.240	0.740	0.016	0.005K	0.023
73/04/20	14 15		0.770	0.440	0.018	0.011	0.035
73/05/04	12 50		0.730	1.000	0.024	0.022	0.063
73/05/25	14 45		0.630	1.200	0.062	0.023	0.063
73/06/10	11 45		0.880	1.260	0.072	0.048	0.110
73/07/04	19 19		1.140	1.745	0.130	0.058	0.130
73/07/27	11 00		0.198	0.780	0.072	0.037	0.095
73/08/31	11 11		0.125	0.600	0.090	0.039	0.115
73/09/24	12 25		0.231	0.460	0.058	0.023	0.070

K VALUE KNOWN TO BE
LESS THAN INDICATED

28

STORET RETRIEVAL DATE 75/02/04

2683B1 L52683B1
42 38 30.0 085 09 30.0
MUD CREEK
26 15 NASHVILLE
1/THORNAPPLE LAKE
BRDG 3 MI NW OF NASHVILLE
11EPALES 2111204
4 0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
72/10/28	10 00		1.500	0.450	0.063	0.060	0.105
72/11/28	14 45		0.430	1.400	0.096	0.014	0.029
73/01/04	15 32		2.800	1.150	0.022	0.030	0.054
73/02/04	17 40		1.620	0.800	0.040	0.018	0.040
73/02/28	08 15		1.240	1.400	0.113	0.018	0.045
73/04/06	12 10		1.060	0.660	0.013	0.010	0.025
73/04/20	14 35		0.460	0.750	0.016	0.016	0.045
73/05/04	12 40		0.710	1.000	0.029	0.050	0.090
73/06/10	12 07		0.700	1.200	0.084	0.102	0.135
73/07/04	14 35		0.820	1.050	0.048	0.080	0.135
73/07/28	11 19		0.410	0.580	0.088	0.060	0.105
73/08/31	11 30		0.370	0.540	0.168	0.064	0.120
73/09/24	13 15		0.273	0.340	0.052	0.032	0.075

STORET RETRIEVAL DATE 75/02/04

25B3C1 LS2B83C1
42 37 30.0 085 11 00.0
BANK CREEK
26 15 NASHVILLE
T/THORNAPPLE LAKE
ROAD CROSSING AT W EDGE OF MORGAN
11EMALES 211204
4 0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
72/10/28	10 10		0.260	0.500	0.056	0.010	0.042
72/11/28	14 55		0.260	0.630	0.014	0.007	0.014
73/01/08	15 22		0.357	0.640	0.015	0.011	0.031
73/02/04	17 25		0.294	0.640	0.028	0.008	0.023
73/02/28	08 05		0.330	0.600	0.048	0.015	0.026
73/04/04	12 18		0.105	0.640	0.020	0.006	0.025
73/04/20	14 45		0.056	0.500	0.014	0.009	0.036
73/05/04	12 10		0.091	0.500	0.018	0.015	0.043
73/05/25	15 10		0.120	2.150	0.069	0.018	0.060
73/06/10	12 14		0.250	1.260	0.044	0.037	0.103
73/07/04	19 45		0.240	0.720	0.027	0.028	0.083
73/07/27	11 27		0.230	0.660	0.020	0.015	0.043
73/08/31	11 37		0.310	0.350	0.052	0.016	0.053
73/09/24	13 05		0.184	0.270	0.019	0.014	0.030

STORET RETRIEVAL DATE 75/02/04

268350 1M268350 MI00470
42 30 00.0 085 06 00.0
NASHVILLE
26 15 NASHVILLE
1//THORNAPPLE LAKE
THORNAPPLE RIVER
11EPALES 2141204
4 0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P	50051 FLOW RATE INST MGD	50053 CONDUIT FLOW-MGD MONTHLY
73/01/05	08 00								
CP(T)-			2.400	9.700	0.147	1.475	2.000	0.203	0.183
73/01/05	16 00								
73/02/05	10 00								
CP(T)-			0.890	13.800	0.155	2.700	12.000	0.150	0.138
73/02/05	16 00								
73/03/01	13 00								
CP(T)-			0.630	19.800	1.100	2.237	3.200	0.126	0.092
73/03/01	15 00								
73/04/17	10 30		0.035	27.300	22.300	7.200	8.200	0.131	0.125
73/05/10	13 30								
CP(T)-			0.570	17.600	0.410	2.900	7.100	0.129	0.136
73/05/10	16 00								
73/06/12	14 30								
CP(T)-			0.650	24.000	1.600	3.200	9.600	0.169	0.098
73/06/12	16 30								
73/08/16	13 00								
CP(T)-			0.048	33.600	12.400		5.300	0.079	0.082
73/08/16	15 00								
73/09/05	10 00		0.250	30.000		5.800		0.061	0.080
73/10/05	09 30		0.480	23.000	5.500	2.400	6.700	0.059	0.063
74/01/07	12 00		0.680	15.000	1.600	3.200	9.700	0.196	0.084
74/02/05	10 35		1.320	14.100	0.290	1.080	2.900	0.226	0.120
74/04/24	09 15		0.640	18.000	0.725	2.100	3.200	0.140	0.229
74/05/03	16 20		0.520	22.000	4.300	3.150	5.900	0.089	0.126